US010150563B2

(12) United States Patent
Harada

(10) Patent No.: US 10,150,563 B2
(45) Date of Patent: Dec. 11, 2018

(54) AUTONOMOUS MOVING MACHINE SYSTEM

(71) Applicant: **Panasonic Intellectual Property Corporation of America**, Torrance, CA (US)

(72) Inventor: **Naoyuki Harada**, Osaka (JP)

(73) Assignee: **PANASONIC INTELLECTUAL PROPERTY CORPORATION**, Torrance, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 38 days.

(21) Appl. No.: **15/458,921**

(22) Filed: **Mar. 14, 2017**

(65) **Prior Publication Data**

US 2017/0285640 A1 Oct. 5, 2017

(30) **Foreign Application Priority Data**

Apr. 1, 2016 (JP) 2016-074458
Nov. 18, 2016 (JP) 2016-225453

(51) **Int. Cl.**
B64C 39/02 (2006.01)
G05B 19/048 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***B64C 39/024*** (2013.01); ***G01S 19/24*** (2013.01); ***G05B 19/048*** (2013.01); ***G05D 1/104*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G01C 21/00; G01C 21/34; G05D 1/00; G05D 1/10; H04W 16/18; H04W 28/02
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2015/0051758 A1* 2/2015 Cho G05D 1/0676 701/16
2015/0057871 A1 2/2015 Ono et al.
(Continued)

FOREIGN PATENT DOCUMENTS

JP 2006-300700 11/2006
JP 2014-149622 8/2014

OTHER PUBLICATIONS

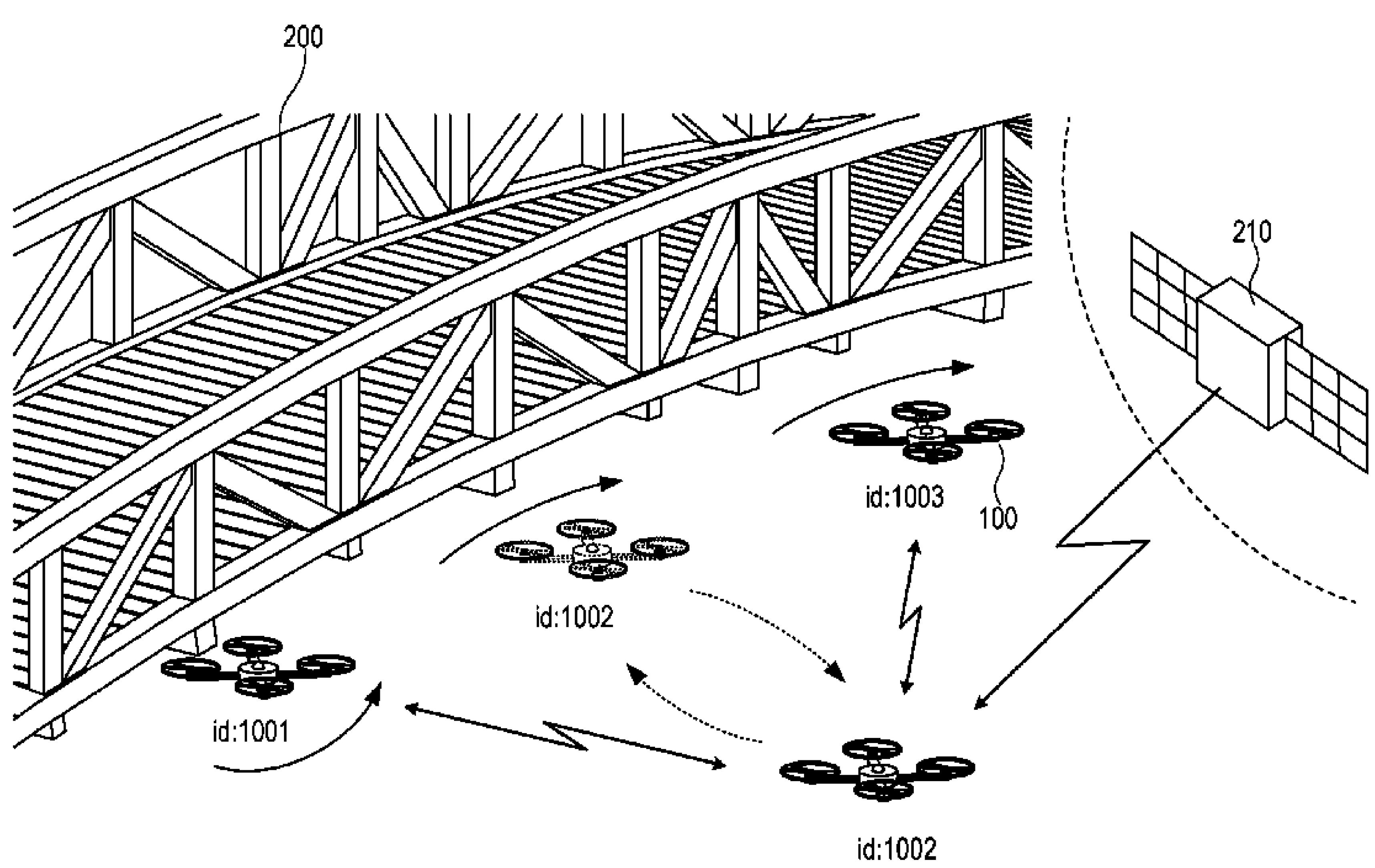
The Extended European Search Report dated Aug. 9, 2017 for the related European Patent Application No. 17162463.8.

Primary Examiner — Thomas G Black
Assistant Examiner — Wae L Louie
(74) *Attorney, Agent, or Firm* — Greenblum & Bernstein, P.L.C.

(57) ABSTRACT

An autonomous moving machine system continuously maintaining moving machines thereof at higher reliability is provided. Each moving machine measures a self-location thereof with a sensor thereof, and autonomously moves to a target location by controlling a mover. Operations of the moving machine includes acquiring sensor information, estimating the self-location in accordance with the sensor information, calculating the reliability of the self-location, transmitting the reliability to the other moving machine. Operations of a particular moving machine further includes recording history information that associates the reliability, the self-location, and an identifier identifying each of the moving machines, selecting a moving machine to restore the reliability in accordance with the history information and moving the selected moving machine to a location where the reliability of the selected moving machine increases.

16 Claims, 8 Drawing Sheets



(51) **Int. Cl.**
G01S 19/24 (2010.01)
G05D 1/10 (2006.01)

(52) **U.S. Cl.**
CPC .. *B64C 2201/108* (2013.01); *B64C 2201/127* (2013.01); *B64C 2201/141* (2013.01); *B64C 2201/145* (2013.01); *G05B 2219/25062* (2013.01)

(58) **Field of Classification Search**
USPC 701/3, 16, 26
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2015/0120126	A1*	4/2015	So	G01C 23/00 701/26
2016/0117932	A1*	4/2016	Park	G01S 19/39 701/3
2017/0069214	A1*	3/2017	Dupray	G08G 5/0021
2017/0094530	A1*	3/2017	Ross	B64C 39/024
2017/0285640	A1*	10/2017	Harada	G05B 19/048
2017/0285661	A1*	10/2017	Harada	B64C 39/024
2017/0344939	A1*	11/2017	Linton	G01S 5/0294
2018/0074520	A1*	3/2018	Liu	G05D 1/104
2018/0091939	A1*	3/2018	Venkatraman	H04W 4/021
2018/0112983	A1*	4/2018	Ahmed	G01C 21/005
2018/0124631	A1*	5/2018	Ramos de Azevedo	H04W 28/0226
2018/0143313	A1*	5/2018	Wetzler	G01S 5/163
2018/0157255	A1*	6/2018	Halverson	B64C 39/024

* cited by examiner

FIG. 1

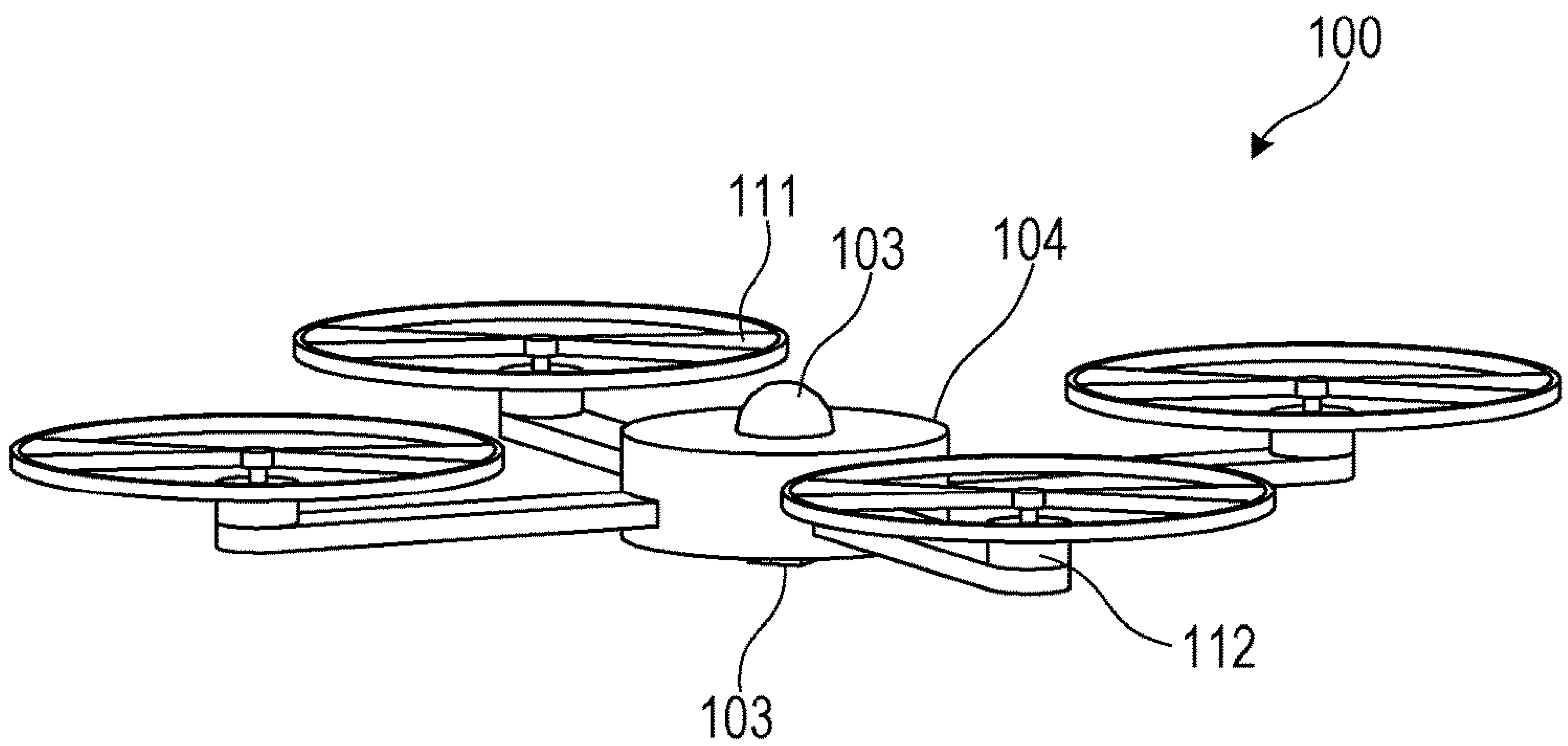


FIG. 2

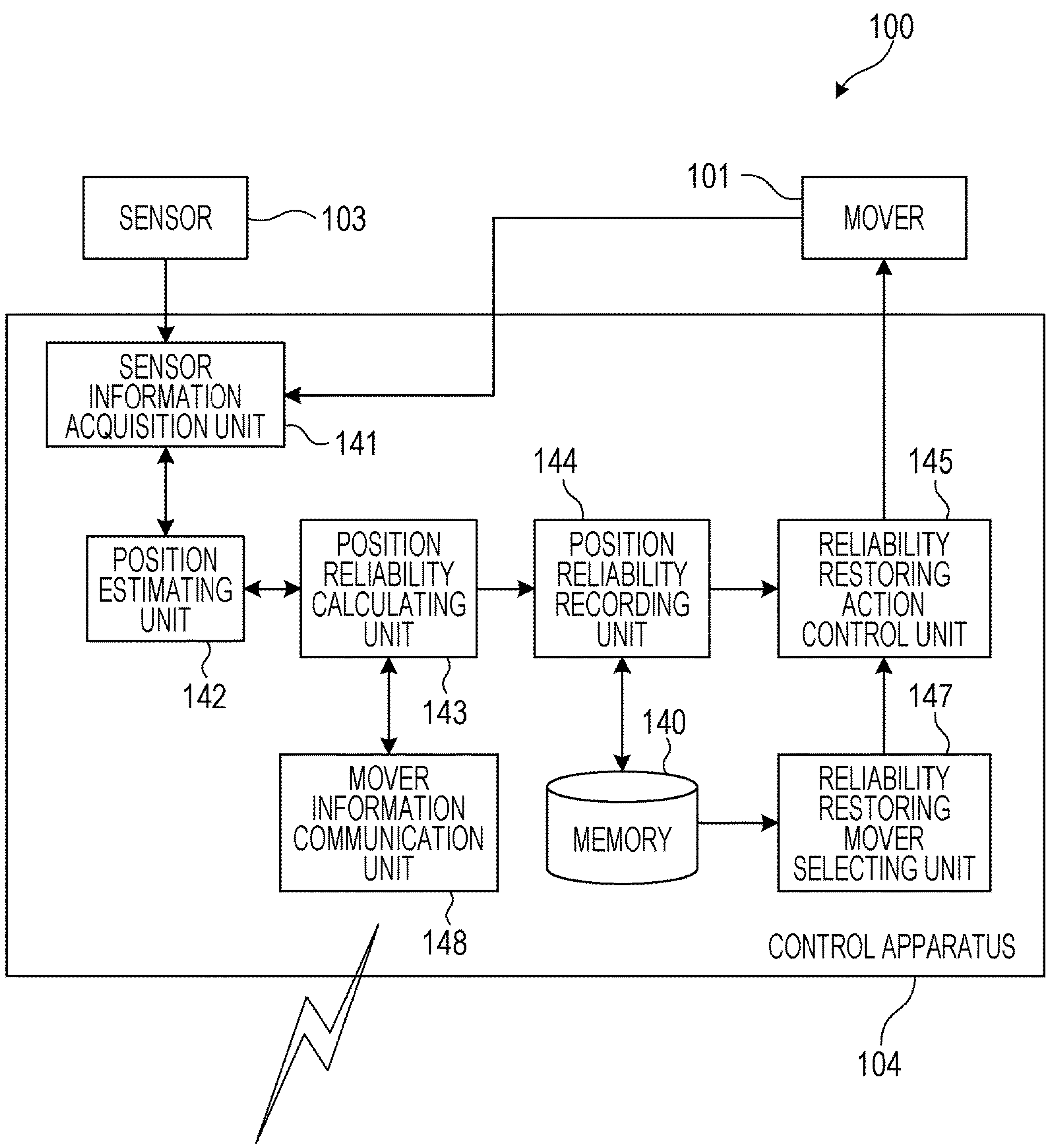

100
SENSOR
103
101
MOVER
SENSOR INFORMATION ACQUISITION UNIT
141
144
145
POSITION ESTIMATING UNIT
POSITION RELIABILITY CALCULATING UNIT
POSITION RELIABILITY RECORDING UNIT
RELIABILITY RESTORING ACTION CONTROL UNIT
142
143
140
147
MOVER INFORMATION COMMUNICATION UNIT
MEMORY
RELIABILITY RESTORING MOVER SELECTING UNIT
148
CONTROL APPARATUS
104

FIG. 3

id = 1001

TIME	COORDINATES	RELIABILITY
0	A	0.9
1	B	0.7
2	C	1.0
3	D	0.8
4	E	0.6
5	F	0.5
6	G	0.3

id = 1002

TIME	COORDINATES	RELIABILITY
0	H	0.8
1	I	0.9
2	J	1.0
3	K	0.8
4	L	0.7
5	M	0.6
6	N	0.5

⋮

FIG. 4

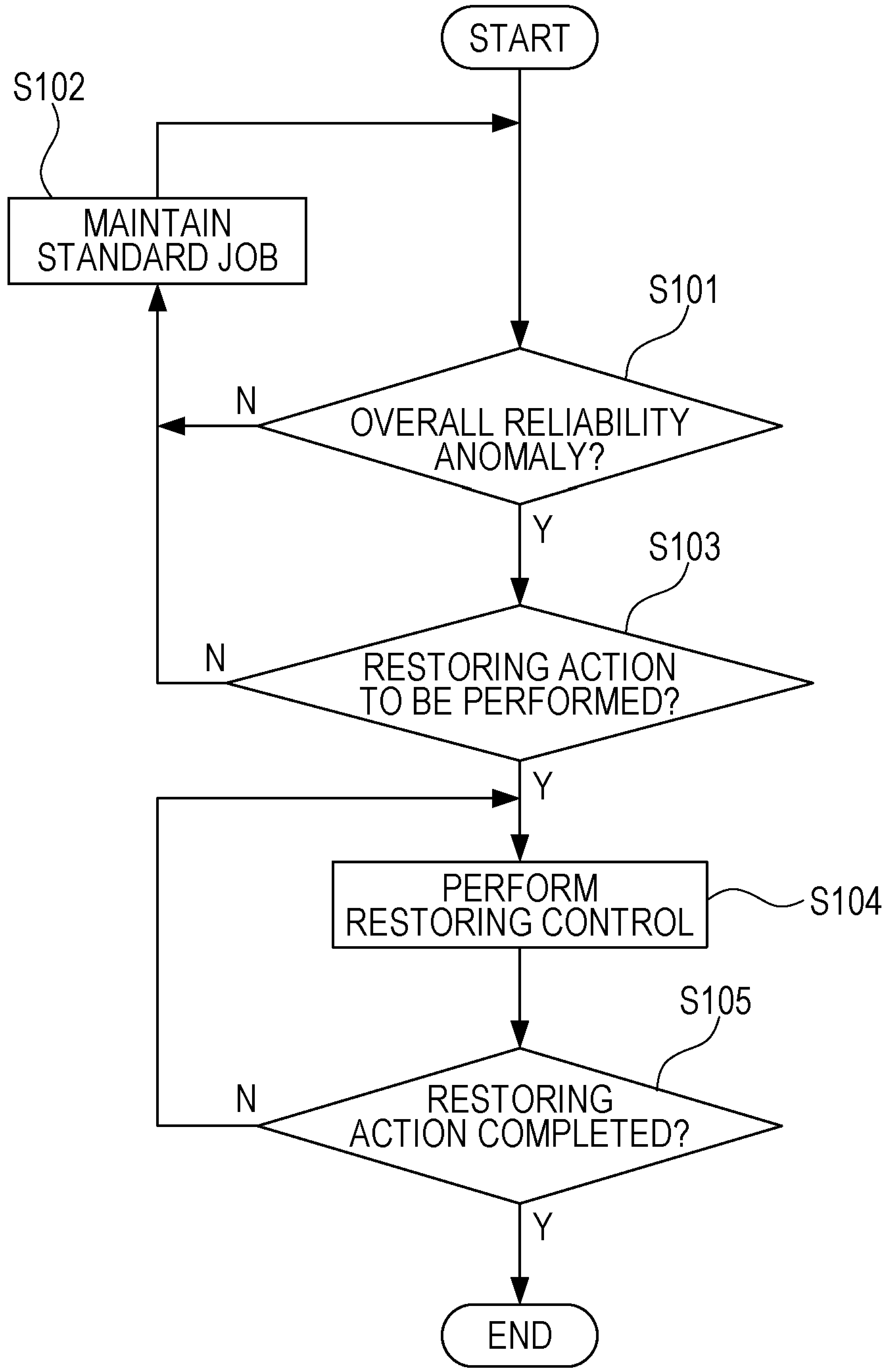

START
S102
MAINTAIN STANDARD JOB
S101
N
OVERALL RELIABILITY ANOMALY?
Y
S103
N
RESTORING ACTION TO BE PERFORMED?
Y
PERFORM RESTORING CONTROL
S104
S105
N
RESTORING ACTION COMPLETED?
Y
END

FIG. 5

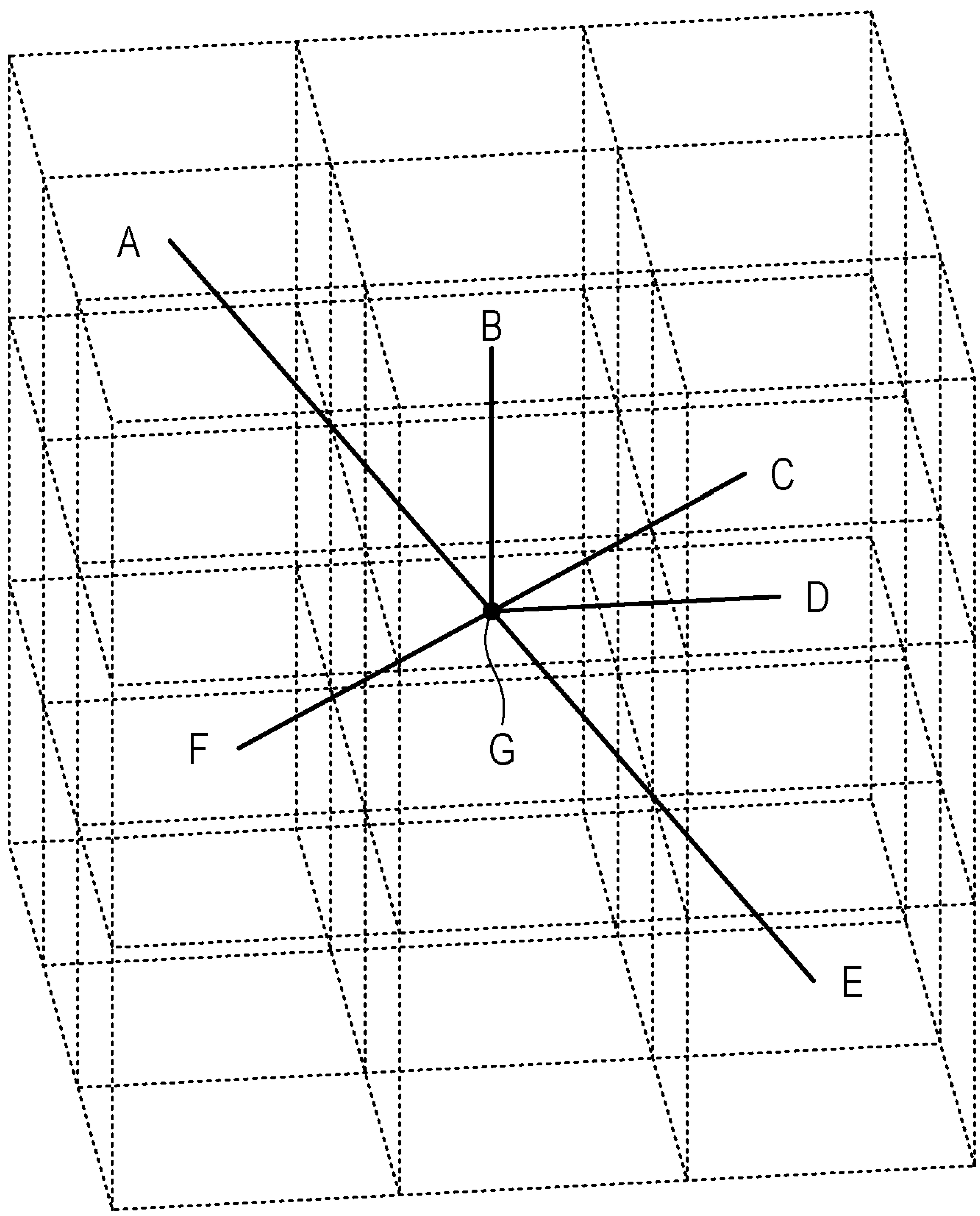


FIG. 6

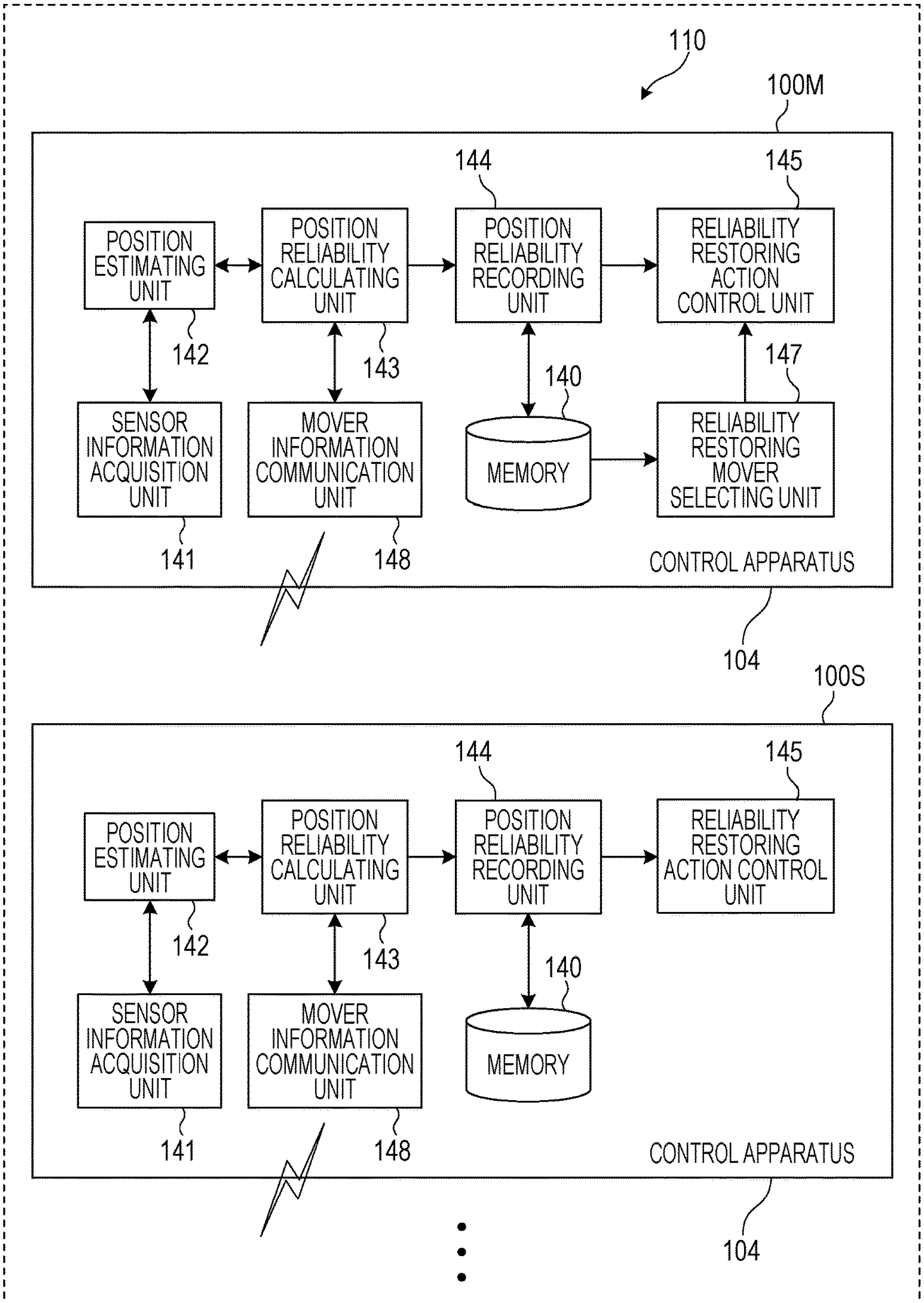

110
100M
144
145
POSITION ESTIMATING UNIT
POSITION RELIABILITY CALCULATING UNIT
POSITION RELIABILITY RECORDING UNIT
RELIABILITY RESTORING ACTION CONTROL UNIT
142
143
147
140
SENSOR INFORMATION ACQUISITION UNIT
MOVER INFORMATION COMMUNICATION UNIT
MEMORY
RELIABILITY RESTORING MOVER SELECTING UNIT
141
148
CONTROL APPARATUS
104
100S
144
145
POSITION ESTIMATING UNIT
POSITION RELIABILITY CALCULATING UNIT
POSITION RELIABILITY RECORDING UNIT
RELIABILITY RESTORING ACTION CONTROL UNIT
142
143
140
SENSOR INFORMATION ACQUISITION UNIT
MOVER INFORMATION COMMUNICATION UNIT
MEMORY
141
148
CONTROL APPARATUS
104

FIG. 7

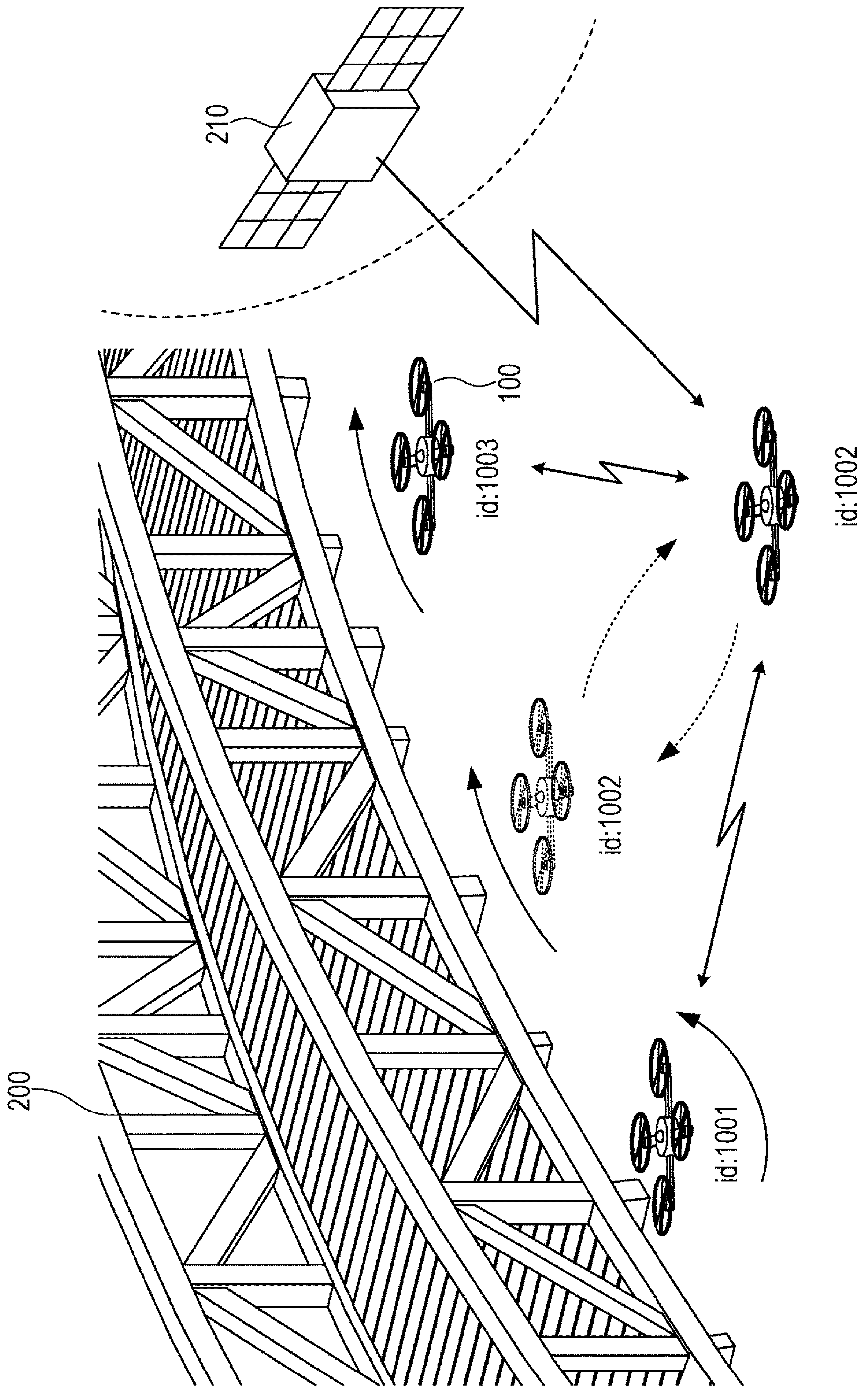
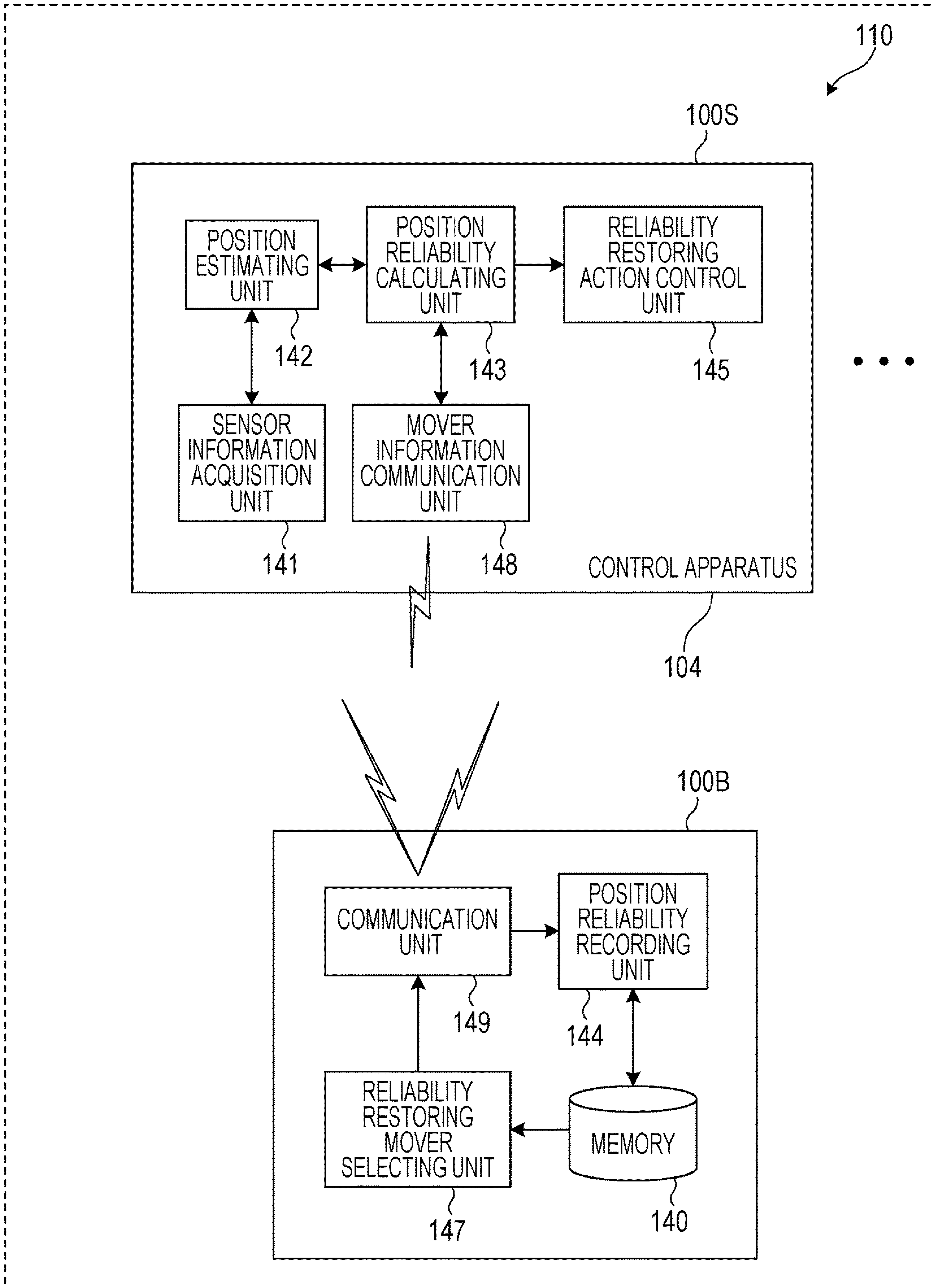


FIG. 8


110
100S
POSITION ESTIMATING UNIT
142
POSITION RELIABILITY CALCULATING UNIT
143
RELIABILITY RESTORING ACTION CONTROL UNIT
145
SENSOR INFORMATION ACQUISITION UNIT
141
MOVER INFORMATION COMMUNICATION UNIT
148
CONTROL APPARATUS
104
100B
COMMUNICATION UNIT
149
POSITION RELIABILITY RECORDING UNIT
144
RELIABILITY RESTORING MOVER SELECTING UNIT
147
MEMORY
140

AUTONOMOUS MOVING MACHINE SYSTEM

BACKGROUND

1. Technical Field

The present disclosure relates to an autonomous moving machine system that includes multiple moving machines, each moving machine autonomously moving to a target location by measuring a self-location with a sensor thereof and by controlling a mover.

2. Description of the Related Art

Moving machines are disclosed that autonomously and individually move to a target location while detecting a self-location thereof using a variety of sensors. Such a moving machine is unable to reach a predetermined location and then to accomplish a target job there if the moving machine fails to acquire the self-location.

Japanese Unexamined Patent Application Publication No. 2014-149622 discloses an autonomous flying robot that independently and autonomously moves while acquiring a self-location in accordance with memorized map information including information concerning obstacles, such as buildings, and measurement results of a sensor. If a relatively large obstacle, such as a truck, appears, an ambient environment may greatly change, possibly causing the autonomous flying robot to be unable to acquire the self-location. In such a case, the autonomous flying robot re-acquires the self-location by increasing a flying height and then performs a target job.

Japanese Unexamined Patent Application Publication No. 2006-300700 discloses another technique. According to the disclosure, multiple moving machines receive information related to self-locations through communication. The moving machines are divided by role. A first type of moving machine is able to acquire the absolutely accurate self-location thereof using satellites. A second type of moving machine acquires the self-location thereof, based on a relative positional relationship with the first type of moving machine. The second type of moving machine that is unable to directly acquire an absolute self-location is able to perform a job, based on the absolute self-location.

The re-acquisition technique disclosed in Japanese Unexamined Patent Application Publication No. 2014-149622 is not applicable to a moving machine that runs on the ground. If there is a bridge or a power-transmission line in the air, it may be difficult to fly the moving machine high above.

In accordance with the technique disclosed in Japanese Unexamined Patent Application Publication No. 2006-300700, if multiple moving machines are present in a wide area, multiple moving machines designed to acquire absolute self-locations may be needed. When an infrastructure inspection job is performed, the use of the moving machines that include a dedicated moving machine that is designed to acquire an absolute self-position leads to an inefficient job. Increasing the efficiency of the job using all moving machines is considered to be difficult.

Even if these techniques are combined, it is still difficult to operate the multiple moving machines in an efficient way.

SUMMARY

One non-limiting and exemplary embodiment provides an autonomous moving machine system that efficiently operates multiple moving machines.

In one general aspect, the techniques disclosed here feature an autonomous moving machine system. The autonomous moving machine system includes multiple moving machines. Each moving machine autonomously moves to a target location by measuring a self-location thereof with a sensor and by controlling a mover. The moving machine includes a sensor information acquisition unit that acquires sensor information related to the self-location and including a relative positional relationship between the sensor and another moving machine, a position estimating unit that estimates the self-location in accordance with the sensor information acquired by the sensor information acquisition unit, a reliability calculating unit that calculates the reliability of the self-location estimated by the position estimating unit, a moving machine information communication unit that exchanges retention information stored thereon with other moving machines, a position reliability recording unit that records in an associated form the reliability calculated by the reliability calculating unit, the self-location estimated by the position estimating unit, and an identifier identifying each moving machine, a reliability restoring moving machine selecting unit that selects, based on information stored on the position reliability recording unit, the moving machine that takes a reliability restoring action, and a reliability restoring action control unit that controls the mover such that the moving machine selected by the reliability restoring moving machine selecting unit moves to a location having higher reliability.

According to the disclosure, a moving machine that moves to a location where a self-location is acquired at higher reliability is selected from a group of multiple moving machines, and selection results are shared among the moving machines. The group of moving machines may thus autonomously move while stably acquiring the self-locations at high reliability. In this way, the moving machines are efficiently operated.

Additional benefits and advantages of the disclosed embodiments will become apparent from the specification and drawings. The benefits and/or advantages may be individually obtained by the various embodiments and features of the specification and drawings, which need not all be provided in order to obtain one or more of such benefits and/or advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a moving machine in an autonomous moving machine system of a first embodiment;

FIG. **2** is a block diagram illustrating part of functional units of each moving machine in the autonomous moving machine system of the first embodiment together with part of mechanical units of the moving machine;

FIG. **3** visually illustrates an example of data stored on a memory;

FIG. **4** is a flowchart illustrating a process of a reliability restoring moving machine selecting unit;

FIG. **5** is a perspective view three-dimensionally illustrating a positional distribution of reliability centered on a self-location;

FIG. **6** is a block diagram illustrating functional units of the moving machine in an autonomous moving machine system of a second embodiment;

FIG. **7** is a perspective view of the autonomous moving machine system that performs bridge inspection; and

FIG. **8** is a block diagram illustrating functional units of the moving machine in an autonomous moving machine system of another embodiment.

DETAILED DESCRIPTION

Autonomous moving machine systems of embodiments of the disclosure is described with reference to the drawings.

The embodiments described below are examples of the moving machine of the disclosure. The embodiments are described for reference purposes, and the scope of the disclosure is not limited by the embodiments but is limited by the claims. Elements in the embodiment not described in an independent claim that indicates a generic concept are not necessarily needed to achieve the object of the disclosure but are used to form a more preferable configuration.

The drawings are highlighted, partially omitted, and diagrammatically adjusted in size ratio to indicate the disclosure, and may be different from real shapes, positional relationship, and size ratio.

First Embodiment

A first embodiment of the disclosure is described below. The first embodiment is related to an autonomous flying object, so-called drone, as a moving machine **100** in an autonomous moving machine system **110**.

FIG. **1** is a perspective view of the moving machine **100** in the autonomous moving machine system **110** of the first embodiment.

FIG. **2** is a block diagram illustrating part of functional units of each moving machine **100** in the autonomous moving machine system **110** of the first embodiment together with part of mechanical units of the moving machine.

Referring to FIG. **1** and FIG. **2**, the moving machine **100** includes multiple rotors (propellers) **111** as the mover **101**, multiple motors **112** that respectively drive the rotors **111**, a sensor **103** that acquires the self-location thereof, and a control apparatus **104** that acquires a signal from the sensor **103** and controls autonomous movement by controlling the motors **112**.

The drone-type moving machine **100** including the multiple rotors **111** individually control the rotational speeds of the rotors **111**, thereby moving the moving machine **100** in a variety of directions (left and right, up and down, back and forth), and adjusting the posture thereof. In accordance with the first embodiment, the control apparatus **104** also acquires from the mover **101**, as sensor information, information concerning a control state of the rotational speed of the rotor **111**, and uses the sensor information as part of information that is used to estimate the self-location of the moving machine **100**.

Any particular device is acceptable as the sensor **103** as long as the device acquires information that estimates the self-location through measurement. More specifically, the sensor **103** may be an inertia measurement unit (IMU) that detects angles and speed thereof in three axial directions, and acceleration in the three axial directions, a pressure meter (altimeter), a flowmeter (anemometer), a global positioning system (GPS) receiver, a laser range finder (LRF), or a depth camera. The sensor **103** may also include a device that acquires, as the sensor information, information related to a relative positional relationship between the self-location and the location of another moving machine **100**. For example, the LRF may be used to acquire, as the sensor information, relative position information that indicates a relative positional relationship of the moving machine **100** with another moving machine **100** present in the ambient space.

The moving machine **100** may include one or more of several types of sensors **103**. The sensor **103** that is to be mounted is selected depending on the type, purpose of movement, and target location of the moving machine **100**.

The control apparatus **104** moves the host moving machine **100** by controlling the mover **101** in response to the information acquired from the sensor **103** or another moving machine **100** as illustrated in FIG. **2**. In other words, the control apparatus **104** is a computer including a central processing unit (CPU) and performs a variety of processes by executing a program stored on a memory **140**. The control apparatus **104** includes, as processing units that are executed by executing the program, a sensor information acquisition unit **141**, a position estimating unit **142**, a position reliability calculating unit **143**, a position reliability recording unit **144**, a reliability restoring action control unit **145**, a reliability restoring moving machine selecting unit **147**, and a moving machine information communication unit **148**.

In accordance with the first embodiment, each moving machine **100** includes the control apparatus **104**. The moving machine **100** is autonomously moved by the control apparatus **104**. The moving machine **100** also moves while recognizing a relative relationship with another moving machine **100**.

The memory **140** may be an information storage device, such as a read-only memory (ROM), or a hard disk drive (HDD). The control apparatus **104** stores the self-location and a program corresponding to each process. The memory **140** also stores position information of a target location, and map information indicating a path and an obstacle.

The sensor information acquisition unit **141** is a processor that acquires a signal t measured by the sensor **103** as the sensor information used to estimate the self-location. The sensor information acquisition unit **141** also acquires, as the sensor information, information acquired from the mover **101**, for example, control information such as the rotational speed of each of the rotors **111**. The sensor information acquisition unit **141** further acquires, as the sensor information, a relative positional relationship with the other moving machines **100**.

The position estimating unit **142** is a processor that estimates as the self-location the present position of the moving machine **100**, based on at least a piece of sensor information and a relationship between the sensor information and the self-location of another moving machine **100** acquired from the other moving machine **100**. In accordance with the first embodiment, the position estimating unit **142** calculates a location as results that the sensor **103** has actually measured, based on multiple pieces of sensor information. The position estimating unit **142** acquires the self-location of the other moving machine **100** from the other moving machine **100**, calculates the measurement location from the sensor information indicating the relative position information related to the other moving machine **100**, and estimates the self-location by combining the measurement locations.

The method of estimating the self-location is not limited to any particular one. For example, a Kalman filter may be used to estimate the self-location, based on a measurement location that is calculated from a signal received from GPS satellites, and a measurement location calculated from sensor information acquired from an inertial measurement device. Simultaneous localization and mapping (SLAM) may be used to estimate the self-location, based on a measurement location that is calculated by checking sensor information from a depth camera against the map information stored on the memory **140** and a measurement location that is calculated from the sensor information from the inertial measurement device.

If the Kalman filter is used as the position estimating unit **142**, the self-location is represented as the normal distribution. The variance of the normal distribution increases in response to elapsed time or an amount of travel from last observation of an absolute position and decreases by observing the absolute position. More specifically, the reliability value increases in response to the elapsed time or the amount of travel from the last observation of the absolute position and decreases by observing the absolute position. The observation of the absolute position may be performed through position fixing using the GPS, or by observing a landmark whose position is known.

The position reliability calculating unit **143** is a processor that calculates the reliability value of the self-location, based on the reliability value of the sensor **103** itself that performs measurement, the reliability value that decreases with time, and an error in the sensor information that is used to estimate the self-location. In accordance with the first embodiment, when the position estimating unit **142** estimates the self-location, based on the measurement location indicating the relative positional relationship with the other moving machine **100** and the self-location of the other moving machine **100**, the position reliability calculating unit **143** calculates the reliability value in combination with the reliability value of the other moving machine **100** that is acquired from the other moving machine **100** via the moving machine information communication unit **148**.

The calculation method of the reliability value performed by the position reliability calculating unit **143** may include using a distribution (such as the normal distribution) that is used when the position estimating unit **142** estimates the self-location and calculating as the reliability value a reciprocal of the variance of the distribution.

The moving machine information communication unit **148** transmits retention information stored thereon to another moving machine **100** included in the autonomous moving machine system **110**.

The retention information includes the self-location, the reliability value of the self-location, the absolute location of the other moving machine **100**, the reliability value of the absolute location, the relative positional relationship between the self-location and the other moving machine **100**, and the reliability value of the relative positional relationship. The retention information, if retained by the moving machine **100**, may be the sensor information acquired by the sensor information acquisition unit **141**, or the signal from the sensor **103**.

The following items of information may be combined as the retention information the moving machine information communication unit **148** transmits or receives. (1) Self-location and the reliability value thereof, (2) absolute location of the other moving machine **100** and the reliability value thereof, (3) relative position between the self-location and the other moving machine **100**, and the reliability value thereof. In accordance with the first embodiment, the moving machine information communication unit **148** transmits and receives signals via radio communication such that the moving machines **100** share with the other moving machine **100** the retention information including the self-locations and the reliability value thereof.

The position reliability recording unit **144** is a processor that records on the memory **140** the self-location (coordinates) estimated by the position estimating unit **142** and the reliability value calculated by the position reliability calculating unit **143** with the self-location and the reliability value in association with each other. In accordance with the first embodiment as illustrated in FIG. **3**, the position reliability recording unit **144** stores on the memory **140** time information in association with the self-location and the reliability. Furthermore, time information, the self-location (coordinates), and the reliability value, transmitted from another moving machine **100**, are stored in association with an identity (id) on the memory **140**. The time information is information indicating time when the position estimating unit **142** estimates the self-location. Referring to FIG. **3**, an identification symbol is attached to information related to time and coordinates, other than the reliability, for identification. The identification symbol has no specific meaning, and different identification symbols could represent the same coordinates.

The reliability restoring moving machine selecting unit **147** is a processor that selects a moving machine **100** that is to perform a reliability restoring action in response to information recorded by the position reliability recording unit **144**. In accordance with the first embodiment, each moving machine **100** in the autonomous moving machine system **110** includes the reliability restoring moving machine selecting unit **147**. If the host moving machine **100** satisfies a predetermined condition, the host moving machine **100** selects itself as a moving machine **100** to restore the liability of the whole autonomous moving machine system **110**.

FIG. **4** is a flowchart illustrating a process of the reliability restoring moving machine selecting unit **147**.

Referring to FIG. **4**, the reliability restoring moving machine selecting unit **147** determines whether the reliability value of the whole autonomous moving machine system **110** satisfies a predetermined condition (S**101**). The evaluation of the overall reliability is performed based on the reliability value of each moving machine **100** stored on the memory **140**. If the whole autonomous moving machine system **110** does not satisfy the predetermined condition (no branch from S**101**), a standard job continues. The standard job includes a job of the moving machine **100** to move to a target location, and a job of performing an inspection operation at the target location.

Examples (patterns) of a specific determination method that is performed when the overall reliability satisfies the predetermined condition are described below.

1.1 The reliability restoring moving machine selecting unit **147** reads from the memory **140** the reliability value of the host moving machine **100** and the reliability value of another moving machine **100**, and performs a statistical operation on the read reliability values, and calculates the variance at each time point. If the calculated variance continues to be equal to or above a first threshold value for a first threshold duration of time, the reliability restoring moving machine selecting unit **147** proceeds to an operation (S**103**) to select a moving machine **100** that is to perform the reliability restoring action.

All the moving machines **100** are determined to be in a state that merely causing the moving machines **100** to mutually observe a positional relationship therebetween and to share observation results through communication is not sufficient to uniformly increase all reliability values.

1.2 The reliability restoring moving machine selecting unit **147** proceeds to an operation (S**103**) to select a moving machine **100** that is to take a reliability restoring action if a difference between a minimum value and a maximum value of the reliability values of all the moving machines **100** continues to be equal to or above a first threshold value for a first threshold duration of time.

In such a case, the same is true, again. All the moving machines **100** are determined to be in a state that merely causing the moving machines **100** to mutually observe a positional relationship therebetween and to share observation results through communication is not sufficient to uniformly increase all reliability values.

1.3 The reliability restoring moving machine selecting unit **147** statistically processes the reliability values of all moving machines **100**. If at least one of the maximum value, mean value, and median thus acquired is lower than a second threshold value, the reliability restoring moving machine selecting unit **147** proceeds to the operation (S**103**) to select the moving machine **100** that is to take the reliability restoring action.

All the moving machines **100** are determined to be in a state that all reliability values are not uniformly increased even if the moving machines **100** measure relative locations and communicate with each other.

1.4 The reliability restoring moving machine selecting unit **147** statistically processes the reliability values of all moving machines **100**, and compares at least one of the resulting maximum value, mean value, and median with the corresponding type of value immediately preceding thereto. If the difference is equal to or above a third threshold value, the reliability restoring moving machine selecting unit **147** determines that all the reliability values sharply drop and then proceeds to the operation (S**103**) to select a moving machine **100** that is take the reliability restoring action.

In such a case, multiple moving machines **100** are determined to be losing track of the self-locations in response to a disturbance, such as a blast of wind.

The moving machine **100** that is to take the reliability restoring action is selected in accordance with information recorded by the position reliability recording unit **144** (S**103**).

Listed below are examples (patterns) of selection conditions when the moving machine **100** that is to take the reliability restoring action is selected. In accordance with the first embodiment, each moving machine **100** including the reliability restoring moving machine selecting unit **147** determines whether the selection condition described below is satisfied. If the moving machine **100** determines that the selection condition is satisfied (yes branch from S**103**), the moving machine **100** autonomously takes a reliability restoring action (S**104**). If the moving machine **100** determines that the selection condition is not satisfied (no branch from S**103**), the moving machine **100** continues a standard job.

2.1 The reliability restoring moving machine selecting unit **147** selects the moving machine **100** that is to take the reliability restoring action in response to the reliability value. For example, the reliability restoring moving machine selecting unit **147** selects a moving machine **100** having a lowest reliability value as the moving machine **100** that is to take the reliability restoring action. The selection condition is applicable if the variance of the reliability values of all the moving machines **100** continues to be equal to or above a first threshold value for a first threshold duration of time, or if a difference between a minimum value and a maximum value of the reliability values of all the moving machines **100** continues to be equal to or above the first threshold value for the first threshold duration of time.

In accordance with the first embodiment, the latest reliability values of the other moving machines **100** acquired by the moving machine information communication unit **148** are compared with the latest reliability value of the host moving machine **100**. If the reliability value of the host moving machine **100** is equal to or lower than the reliability values of the other moving machines **100**, the host moving machine **100** autonomously starts the reliability restoring action (S**104**).

2.2 The reliability restoring moving machine selecting unit **147** selects the moving machine **100** that is to take the reliability restoring action depending on battery remaining power of a battery that feeds power to the moving machine **100**. For example, a moving machine **100** having highest remaining battery power may be selected as the moving machine **100** that is to take the reliability restoring action. The selection condition is applicable if at least one of the maximum value, the mean value, and the median of all the reliability values of the moving machines **100** is lower than a second threshold value. Since this method makes battery remaining power values of the moving machines **100** uniform, a long operation time may be ensured.

In accordance with the first embodiment, the moving machine information communication unit **148** communicates information indicating battery remaining power in addition to the self-location and the reliability value o the other moving machines **100** to share these pieces of information. Each moving machine **100** compares the latest battery remaining power thereof with the latest remaining power of the other moving machines **100**. If there is no other moving machine **100** having remaining battery power higher than the remaining battery power of the moving machine **100**, the moving machine **100** autonomously starts the reliability restoring action (S**104**).

2.3 The reliability restoring moving machine selecting unit **147** selects a moving machine **100** in accordance with the reliability value. For example, the reliability restoring moving machine selecting unit **147** selects a moving machine **100** having a highest reliability value as the moving machine **100** that is to take the reliability restoring action. The selection condition is applicable if at least one of the maximum value, the mean value, and the median of all the reliability values of the moving machines **100** is lower than the second threshold value.

In accordance with the first embodiment, the moving machine information communication unit **148** compares the latest reliability value of the moving machine **100** with the latest reliability values of the other moving machines **100** acquired by the moving machine information communication unit **148**. If there is no other moving machine **100** having the reliability value higher than the reliability value of the moving machine **100**, the moving machine **100** autonomously starts the reliability restoring action (S**104**).

2.4 The reliability restoring moving machine selecting unit **147** selects a moving machine **100** closest to a region having the highest reliability value as the moving machine **100** that is to take the reliability restoring action. The selection condition is applicable if at least one of the maximum value, the mean value, and the median of all the reliability values of the moving machines **100** is lower than the second threshold value. In this case, an amount of energy for the reliability restoring action is minimized, and time for the reliability restoring action is shortened.

In accordance with the first embodiment, each moving machine **100** collects the reliability values of all the moving machines **100** from the memory **140**, and searches for a region having the highest reliability value. The moving machine **100** calculates the Euclidean distance between coordinates of the region having the highest reliability value and the self-location of another moving machine **100**, and compares the calculated Euclidean distance with the Euclidean distance between the coordinates of the region having the highest reliability value and the self-location. If there is no Euclidean distance that is shorter than the Euclidean distance between the coordinates of the region having the highest reliability value and the self-location, the moving machine **100** autonomously starts the reliability restoring action (S**104**).

Examples (patterns) of specific control methods of the reliability restoration by the moving machine **100** selected by the reliability restoring moving machine selecting unit **147** are described below.

The reliability restoring action control unit **145** is a processor that controls the mover **101** such that the moving machine **100** selected by the reliability restoring moving machine selecting unit **147** moves to a location having a higher reliability value in response to information recorded on the position reliability recording unit **144**.

3.1 The reliability restoring action control unit **145** controls the mover **101** in response to the reliability value stored on the memory **140** such that the moving machine **100** successively moves along the self-locations recorded on the memory **140** until the reliability value is equal to or above a predetermined threshold value (S**104**).

The control method is described with reference to data of FIG. **3**. It is assumed that the present time is 6, the threshold value is 0.8, and the identifier indicating the selected moving machine **100** is 1001. By controlling the mover **101**, the reliability restoring action control unit **145** moves the moving machine **100** such that the moving machine **100** is routed along G (reliability value of 0.3)→F (reliability value of 0.5)→E(reliability value of 0.6)→D(reliability value of 0.8). More specifically, the moving machine **100** changes back to the one that has selected the path that reaches coordinates having the reliability value equal to or above the threshold value.

The self-location is then re-estimated at a coordinate location having a higher reliability value. Using the moving machine **100**, another moving machine **100** estimates the self-location thereof again, thereby increasing the reliability values of all the moving machines **100**.

The reliability restoring action described above is effective when the moving machine **100** moves in a given space for the first time, or when the reliability values sharply drops because of an occurrence of sudden wind.

3.2 The reliability restoring action control unit **145** controls the mover **101** such that the moving machine **100** moves to a location that is closest to the current location and where the reliability value stored on the memory **140** is equal to or above a predetermined threshold value.

More specifically, as illustrated in FIG. **5**, the memory **140** stores coordinate locations that are present in an ambient area centered on the self-location of the moving machine **100** selected when the reliability value satisfies the predetermined condition (present time **6**) (at up and down, back and forth, and left and right positions) and that have the reliability value equal to or above the first threshold value (0.8). Those coordinate locations may be A, C, and D, for example, and extracted from the reliability values of all the moving machines **100** according to the information stored on the memory **140**. The Euclidean distance between each coordinate location and the current self-location is calculated. The mover **101** is controlled such that the moving machine **100** linearly moves to a coordinate location having the shortest Euclidean distance (D, for example). The moving machine **100** thus reaches the coordinate location D.

The moving machine **100** reaches the coordinate location having the highest reliability value within a short period of time. The moving machine **100** estimates the self-location at the coordinate location again, and may shift to an action to perform a standard job within a short period of time.

Such a reliability restoring action is effective when the moving machine **100** performs an inspection operation within a narrow area.

3.3 The reliability restoring action control unit **145** controls the mover **101** such that the moving machine **100** moves to a location where a selected moving machine **100** has a past reliability value equal to or above a predetermined threshold value and that is associated with time information having time closest to the present time.

The control method is described with reference to data of FIG. **3**. It is assumed that the present time is 6, and the threshold value is 0.8. The reliability restoring action control unit **145** checks the reliability values at id 1001 along time series 6 (reliability value 0.3)→5 (reliability value 0.5)→4 (reliability value 0.6)→3 (reliability value 0.8), and controls the mover **101** such that the moving machine **100** moves to a coordinate location having a reliability value equal to or above the threshold value, namely, the coordinate location (D). The moving machine **100** thus moves to the coordinate location D.

As described above, the moving machine **100** reaches the coordinate location having the highest reliability value within a short period of time. The moving machine **100** estimates the self-location at the coordinate location again, and may shift to an action to perform a standard job within a short period of time.

Such a reliability restoring action is effective when the moving machine **100** moves within a wide space with a small number of obstacles.

Second Embodiment

An autonomous moving machine system **110** of a second embodiment of the disclosure is described below. Elements identical in operation, function, shape, mechanism, and structure to those of the first embodiment are designated with the same reference numerals, and the discussion thereof is omitted. The following discussion focuses on a difference between the first embodiment and the second embodiment, and the same discussion is not repeated.

FIG. **6** is a block diagram illustrating functional units of the moving machine in an autonomous moving machine system of the second embodiment.

The autonomous moving machine system **110** of the second embodiment includes as moving machines **100** a master moving machine **100**M including a reliability restoring moving machine selecting unit **147** in control apparatus **104** and a slave moving machine **100**S that moves in response to a command from the master moving machine **100**M.

The master moving machine **100**M collects the self-locations and reliability values of all the moving machines **100** via the moving machine information communication unit **148**. In a similar way to the first embodiment or in response to a determination result described below, the reliability restoring moving machine selecting unit **147** in the master moving machine **100**M selects a moving machine **100** that is to take the reliability restoring action.

Described below are examples (patterns) of selection conditions according to which the moving machine **100** to perform a reliability restoring action different from the reliability restoring action of the first embodiment is selected.

2.5 The reliability restoring moving machine selecting unit **147** selects at least one moving machine **100** that is to take the reliability restoring action from among the moving machines **100** present in a region where moving machines **100** having a lower reliability value aggregate. The master moving machine **100**M transmits through the moving machine information communication unit **148** information indicating that the moving machine **100** has been selected. The selection condition is applicable if the variance of the reliability values of all the moving machines **100** continues to be equal to or above a first threshold value for a first threshold duration of time, or if a difference between a minimum value and a maximum value of the reliability values of all the moving machines **100** continues to be equal to or above the first threshold value for the first threshold duration of time.

In accordance with the second embodiment, coordinates associated with a reliability value equal to or below a predetermined threshold value are extracted from the latest reliability values and the coordinates of the self-locations of all the moving machines **100** collected by the moving machine information communication unit **148**. A specific unit region having the largest number of coordinates is identified as a region where moving machines **100** having lower reliability values aggregate. One moving machine **100** is selected from the moving machines **100** at the coordinates within the identified region. The moving machine information communication unit **148** transmits information indicating that the moving machine **100** has been selected. If the master moving machine **100**M is selected, transmitting the information concerning the master moving machine **100**M is not needed.

2.6 The reliability restoring moving machine selecting unit **147** selects a moving machine **100**, in a region where moving machines **100** aggregate, as the moving machine **100** that is to take the reliability restoring action. Using the moving machine information communication unit **148**, the master moving machine **100**M transmits to the moving machine **100** information that the moving machine **100** has been selected. The selection condition of the moving machine **100** is applicable if at least one of the maximum value, the mean value, and the median of the reliability values of all the moving machines **100** is below a second threshold value.

In accordance with the second embodiment, a specific unit region having the largest number of coordinates therewithin is identified as a region where moving machines **100** having lower reliability values aggregate by referencing the coordinates of the latest self-locations of all the moving machines **100** collected by the moving machine information communication unit **148**. One moving machine **100** is selected from the moving machines **100** at the coordinates within the identified region. The moving machine information communication unit **148** transmits information indicating that the selected moving machine **100** has been selected.

The process workload on the control apparatus **104** of the slave moving machine **100**S is thus reduced by causing the master moving machine **100**M in a centralized fashion to evaluate the reliability values of all the moving machines **100** and to select the moving machine **100** that is to take the reliability restoring action.

EXAMPLES

Specific examples of the autonomous moving machine system **110** are described below.

FIG. **7** is a perspective view of the autonomous moving machine system **110** that performs a bridge inspection job.

Referring to FIG. **7**, in this example, the moving machine **100** is a drone, and the autonomous moving machine system **110** includes multiple drone-type moving machines **100**. The job performed of the autonomous moving machine system **110** is an inspection job to be performed on the underside of a bridge **200**. Each moving machine **100** having an inspection camera mounted on top thereof photographs the underside of the bridge **200**. The moving machines **100** perform this job on their respective portions of the underside of the bridge. Cracks on the structure of the bridge **200** may be detected by referencing a video captured by each moving machine **100** and the location of the captured video.

Each moving machine **100** estimates the self-location and performs the job using the Kalman filter in accordance with the sensor information from the sensor **103**, such as IMU or GPS, and the relative positional relationship of the moving machine **100**. As the job is in progress, the reliability of the whole autonomous moving machine system **110** decreases. For example, the variance of the reliability values of the self-locations of all the moving machines **100** may continue to be equal to or above a first threshold value for a first threshold duration of time or longer. In such a case, each moving machine **100** communicates with the other moving machines **100** via the moving machine information communication unit **148** and selects a moving machine **100** that is closest to a region having a higher reliability value (in this example, the moving machine **100** having id **1002**).

In response to the information stored on the memory **140**, the reliability restoring action control unit **145** in the selected moving machine **100** controls the mover **101** such that the moving machine **100** moves to the region having the higher reliability value, for example, the region where signals from GPS satellites **210** are received.

The moving machine **100** that moves by controlling the mover **101** restores the reliability value of the self-location and returns back to the location where the moving machine **100** starts the reliability restoring action, and then photographs the bridge **200**.

The moving machine **100** increases the reliability value of the other moving machines **100** by transmitting the new self-location and reliability value to the other moving machines **100**. The overall reliability of the autonomous moving machine system **110** is thus increased.

As described above, the autonomous moving machine system **110** may perform the job efficiently while keeping the system reliability at a higher level.

The disclosure is not limited to the embodiments. For example, an embodiment of the disclosure may be configured by using some of the elements described in this specification in any combination, or by deleting some of the elements. The embodiments may be modified in a manner recognized by ordinarily skilled artisans within the scope of the disclosure, namely without departing from the scope of the disclosure defined by the claims. The modifications fall within the scope of the disclosure.

In the above discussion, the master moving machine **100**M performs the standard job as the slave moving machine **100**S does. Alternatively, the master moving machine **100**M may only manage the slave moving machine **100**S without performing the standard job.

As illustrated in FIG. **8**, the autonomous moving machine system **110** may include a fixed apparatus **1006** that includes the position reliability recording unit **144**, the reliability restoring moving machine selecting unit **147**, and a communication unit **149** that is communicable with the moving machine information communication unit **148**. In this case, the moving machines **100** are all slave moving machines **100**S. The fixed apparatus **1006** acquires the self-locations and the reliability values from the slave moving machines **100**S via communication, selects in accordance with these pieces of information a slave moving machine **100**S whose reliability is to be restored, and transmits to the selected slave moving machine **100**S information indicating that the slave moving machine **100**S has been selected. In this case, as well, the slave moving machine **100**S may not necessarily have to include the position reliability recording unit **144** and the memory **140**.

The fixed apparatus **1006** may collect the sensor information via the sensor information acquisition unit **141** and the moving machine information communication unit **148** in each slave moving machine **100**S, and may calculate the self-locations and the reliability values of all the moving machines **100**S. The reliability restoring moving machine selecting unit **147** in the fixed apparatus **100**B may select in accordance with the reliability values a slave moving machine **100**S that is to take the reliability restoring action.

In accordance with the embodiments, the moving machine **100** is an autonomous flying object that freely and three-dimensionally moves, namely, is a drone flying in the air. The moving machine **100** is not limited to the drone. The moving machine **100** may be an autonomous vehicle running on the ground, or an autonomous ship cruising on the sea.

The sensor **103** that acquires information contributing to estimating the self-location is not limited to any particular type. The sensor **103** may further include any sensor that has not been described herein.

All processes are implemented by the control apparatus **104** alone. Alternatively, the processes may be distributed among multiple controllers, and information may be exchanged among the controllers via mutual communication.

The self-location and the reliability value are successively calculated during the reliability restoring action, and the reliability restoring action may be ended when the acquired reliability value exceeds a predetermined value. Alternatively, the reliability restoring action may be ended when the self-location matches the target location.

After the reliability is restored, the moving machine **100** may return back to the location where the reliability restoring action starts. Alternatively, the moving machine **100** may directly move to a target location from the location where the reliability is restored.

The disclosure finds applications in vehicles, trains, ships, air planes, and vacuum cleaners, each of these moving in an autonomous fashion.

What is claimed is:

1. A system comprising:

moving machines, each moving machine of the moving machines configured to move to a target location by autonomous control, each moving machine comprising:

a sensor which obtains a self-location of the moving machine;

a processor; and

a memory storing a computer program which, when executed by the processor, causes the processor to perform operations, the operations including:

acquiring, from the sensor, sensor information related to the self-location of the moving machine, the sensor information including a relative positional relationship between the moving machine and another moving machine of the moving machines;

estimating the self-location of the moving machine based on the acquired sensor information;

calculating a reliability of the estimated self-location of the moving machine, and storing the reliability associated with the self-location on the moving machine;

transmitting the stored reliability associated with the self-location of the moving machine, to the other moving machine,

wherein the operations performed by a particular moving machine of the moving machines further include,

recording history information that associates the reliability, the self-location, and an identifier identifying each of the moving machines;

selecting, from the moving machines, a moving machine to restore the reliability in accordance with the history information; and

moving the selected moving machine to a location where the reliability of the self-location of the selected moving machine increases.

2. The system according to claim **1**,

wherein the reliability decreases in response to an elapsed time from or in response to a travel amount of the moving machine from when the sensor acquires an absolute position of the moving machine, and the reliability increases when the sensor acquires the absolute position of the moving machine, and

wherein the absolute position is measured by using a GPS or a land mark at a known position.

3. The system according to claim **2**,

wherein the moving machine to restore the reliability is selected in accordance with a statistical quantity that is calculated from all reliabilities related to the moving machines.

4. The system according to claim **3**,

wherein the statistical quantity includes a variance or a difference between a maximum value and a minimum value of the all reliabilities, and

wherein the moving machine to restore the reliability is selected when the variance or the difference between the maximum value and the minimum value of the all reliabilities remains at or above a first threshold value for longer than a first time threshold.

5. The system according to claim **3**,

wherein the statistical quantity includes a maximum value, a mean value, and a median of the all reliabilities, and

wherein the moving machine to restore the reliability is selected when at least one of the maximum value, the mean value, and the median of the all reliabilities sharply falls.

6. The system according to claim **3**,

wherein the statistical quantity includes a maximum value, a mean value, and a median of the all reliabilities, and

wherein the moving machine to restore the reliability is selected when at least one of the maximum value, the mean value, and the median of the all reliabilities is lower than a second corresponding threshold value.

7. The system according to claim **2**, wherein each of the moving machines is a drone.

8. The system according to claim **7**, wherein the sensor information is a number of rotation of a rotor of the drone.

9. The system according to claim **1**,

wherein the moving machine to restore the reliability is selected in accordance with the reliability.

10. The system according to claim **9**,

wherein the moving machine, having a minimum reliability of all reliabilities related to the moving machines, is selected as the moving machine to restore the reliability.

11. The system according to claim **9**,

wherein the moving machine, having a maximum reliability of all reliabilities related to the moving machines, is selected as the moving machine to restore the reliability.

12. The system according to claim 1, wherein the moving machine having maximum remaining battery power is selected as the moving machine to restore the reliability.

13. The system according to claim 1, wherein the moving machine, positioned closest to a region having a reliability higher than a predetermined value, is selected as the moving machine to restore the reliability.

14. The system according to claim 1, wherein the moving machine, present in a region where multiple moving machines each having a reliability lower than a predetermined value are present, is selected as the moving machine to restore the reliability.

15. The system according to claim 1, wherein a moving machine, present in a region where multiple moving machines are present, is selected as the moving machine to restore the reliability.

16. The system according to claim 1, wherein the self-location is estimated using normal distribution, and wherein the reliability of the select-location is calculated by calculating a reciprocal of a variance of the normal distribution.

* * * * *